DOCUMENT RESUME

ED 179 387 SE 029 211

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TITLE Development of Reasoning in Science (DORIS): A Course in Abstract Thinking.
PUB DATE 79
NOTE 60p.; Not available in hard copy due to marginal legibility of original document

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS *Cognitive Development; Cognitive Style; College Science; Course Content; Course Descriptions; Course Evaluation; *Educational Research; Higher Education; Learning Processes; *Problem Solving; Science Education; *Science Instruction; Student Evaluation; Teaching Methods; Thought Processes; Undergraduate Study

ABSTRACT

Presented is a report on a course for undergraduate students which is designed to increase their intellectual abilities early in their college careers. The report gives the characteristics of concrete thought and formal reasoning, followed by an explanation of the process involved in data collecting and the data itself. The authors suggest that the course will develop intellectual ability of science majors at the university level. An appendix includes a modified version of the Flanders Interaction Instrument. (SA)

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# DEVELOPMENT OF REASONING IN SCIENCE (DORIS): A COURSE IN ABSTRACT THINKING

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SE 029 211

DEVELOPMENT OF REASONING IN SCIENCE

(DORIS)

A Course In Abstract Thinking

Many college science departments are making inadequate evaluations of the logical thinking abilities of their students. It appears that most college science courses have not taken into account the research on learning and intellectual development. Recent studies have shown that the difficulty students have in problem solving is a result of their inability to use the strategies of abstract thinking confidently and reliably. A typical freshmen functions at the level of concrete experiences. He comes to college with inadequate skills to argue logically about the importance of a given principle when the context in which it is used is slightly altered. Many times he is unable to think logically about the simplest kind of problem.

Many prominent psychologists such as Bruner and Piaget have attempted to define formal or abstract thinking. The work of Inhelder and Piaget (1958) is the primary source for formal thinking. Their research presents the characteristics of concrete and formal thinking and develops a variety of tasks designed to elicit the sophisticated and abstract thought processes of students who are formal thinkers. A major result of their research efforts is a description of the changes that

characterize a person moving from the stage of concrete thinking to the stage of formal thinking.

In the stage of concrete thought, an individual uses logic based on his own experiences. He can make simple generalizations and classifications and follow step-by-step instructions, as in a recipe. Since a concrete thinker must have direct experiences, he can understand concepts only in terms of familiar actions and experiences. Finally, he is not spontaneously aware of his own reasoning.

At the stage of formal thought the individual recognizes and interprets functional relationships even in situations described by abstract variables. He can imagine all possible combinations of theoretical conditions, formulates hypotheses, and devises experimental tests. He understands concepts defined in terms of other concepts or through abstract relationships. Finally he is aware and critical of his own reasoning. He has developed a wide repertoire of problem solving skills.

From their research on formal operations, Inhelder and Piaget found that children as young as 11 or 12 begin to acquire formal operational skills and formal thought processes were regularly observed in 16 to 18 year old adolescents. However, investigations conducted with college students to determine their level of thinking has revealed a different picture. McKinnon (1971), using Piagetian tasks, tested college freshmen at a large southwestern university. He found that 50 percent of these students were operating at Piaget's stage of concrete

thinking. Another 25 percent were in transition from concrete to formal thought. Griffiths (1973) reported that his freshmen subjects, many of whom were physics and chemistry majors, were unable to use formal operational processes in solving problems. Tomilinson-Keasey (1972) reported that less than 50 percent of her female college students were able to exhibit formal thought on Piagetian tasks administered to them. In fact, Langer and Kuhn (1971) have estimated that many adults have not yet reached this level of formal thought.

If one closely examines the level of instruction of most college science courses, some interesting information is found. For example, many concepts and principles in the various scientific disciplines are developed through formal thinking processes. It appears as if the thinking level of many college students doesn't coincide with the level of presentation of concepts by the college science instructor. Many professors make the assumption that their students can use abstract thinking skills in dealing with the course content. From the data of the recent studies cited, it is clear that they cannot. They are not intellectually ready to think about abstractions! High rates of course failures, increased college dropouts, and dislike among students for these abstract courses are fairly commonplace in most institutions of higher learning, especially in the sciences. The cry of many college science teachers that students can't think could be attributed to this intellectual dichotomy: course content presentation at one level of intellectual thinking and student's thinking ability at another level.

The questions that arise as a result are quite provocative. What kinds of concepts, courses, experiences and programs in science are likely to enhance intellectual development in college students? How can science instructors at the college level develop teaching strategies that ease the transition from concrete to formal thinking? What kinds of experiences are necessary and how many? How long will it take? Can we measure this intellectual growth? How do you make college professors aware of the intellectual growth patterns of their students? Can a science curriculum be reorganized around specific thinking skills rather than scientific content? If so, will as much subject matter learning take place? Could the function of general education in science be designed to systematically teach the non-science major abstract thinking skills?

As a result of the above mentioned questions a course in abstract thinking for college science majors was developed. The development of this course took approximately one year. Five abstract thinking skills were selected to form the nucleus of the course. They were: combinatorial logic, correlation, hypothetical-deductive reasoning, isolation and control of variables, and proportional reasoning. Scientists from chemistry, earth science, mathematics, and physics were the designers of the course. They selected concepts from the first year course offerings in their respective departments for use in the course in abstract thinking. The course was not typical since it was designed along the dimensions of the thinking skills

mentioned previously rather than particular science concepts. This does not mean that subject matter knowledge was not an important outcome of the learning experience for students. The main focus of the course was the development of the reasoning patterns of students.

Because thinking skill development was the primary objective of the course, the learning situation for each science concept had to be developed in a concrete manner. That is, the learner must be able to use logic based on his own experiences. Students must be able to follow step-by-step instructions in a problem-solving environment. As students develop the thinking skills associated with concrete thinking processes, the sequencing moves to a higher level. That is, the learner can be recycled through new problem-solving situations. This time the reasoning skills required to solve problems are much more sophisticated. Hopefully, by spiralling back on the thinking skills using a variety of science content intellectual growth can be enhanced.

An example of this approach can be demonstrated by using some of the content from physics. Students manipulate a cart and incline plane in a laboratory environment. This content can be utilized to teach some of the critical aspects of proportional reasoning. Students can learn to identify variables, establish correspondence between variables, set up ratio relationship variables, and finally develop a relationship between two ratios using direct proportionality.

By changing the content, students can develop a deeper understanding of the more sophisticated elements of proportional reasoning. Using a balance beam apparatus students learn to extend their previous knowledge to a situation which includes both relevant and irrelevant variables and relationships among variables based on inverse proportionality.

The course was built around an instructional strategy called "The Learning Cycle." This cycle is made up of three sequential components: exploration, invention, and discovery. Each component contains a set of materials-based laboratory investigations. The Learning Cycle is a series of teaching strategies that allows students to enhance their intellectual growth through a process called self-regulation.

Every lesson in the course begins with a set of exploration activities. These activities are designed to provide an optimal mismatch between the student's reasoning level and the level of reasoning required in the lesson. These activities challenge the student's reasoning abilities, leading to what Piaget has called disequilibrium. This disequilibrium heightens the curiosity and motivation of the student.

The next phase of the lesson, called invention, develops a concept, skill, or idea for the students. It provides an anchor for the experiences students acquire during exploration. Discovery, the last phase of the lesson, asks students to rearrange what they learned during exploration and invention in new and different ways. This requires the students to apply

newly acquired thinking skills to accomplish this task. Using thinking skills in this manner is called self-regulation and is the key to intellectual growth in the course.

Consider what goes into exploration, invention, and discovery: imagination, analysis, comparison, synthesis, evaluation, generalization, inference, and deduction. The foregoing list of mental activities would seem to represent a fairly adequate operational definition of thinking. In other words, science if taught from an exploration, invention, and discovery frame of reference, is an excellent vehicle for students to develop their thinking abilities. Since the foregoing operational definition of thinking was derived from viewing scientific experiments and activities, developing facility with that definition also represents adequate and responsible attention to the discipline itself.

Over eighty lessons have been field tested in a classroom setting. Based upon evaluation of the field testing, lessons were modified and redesigned as necessary. Different lesson sequencing patterns were tried and evaluated. Presently, thirty-nine are being used in the course. The sequencing of these lessons is included in the Appendix to this paper. The link between scientific content and thinking skills is clear.

The course is undergoing its final evaluation during the 1979-1980 academic year. The following is a report of the evaluation of the course.

During the Fall of 1978, thirteen students were enrolled in the course. Nine were males, four females. The average age of the students was 18.38 years, with an age range from 17 to 21 years. Eleven were freshmen, one a sophomore and one

a junior. All students were declared science majors: 5 biology, 4 computer science, 3 engineering, and 1 earth science.

Evaluation Instruments

Two evaluation instruments were used: (1) Formal Operational Measures and (2) Learning Style Inventory. Each instrument was administered both at the beginning and the end of the semester course in a pre-post evaluation design.

1. Formal Operational Measures. This instrument consisted of a battery of five puzzles developed by Campbell (1977). Each puzzle was keyed to one of the five reasoning abilities that were the basis of the course.

| Formal Operational Ability | Puzzle |
|---|---|
| 1. Hypothetical-deductive reasoning | Islands Puzzle |
| 2. Isolation and control of variables | Flexibility of Rods |
| 3. Combinatorial reasoning | Chemicals (Pre)<br>Algae (Post) |
| 4. Proportional reasoning | Balance |
| 5. Correlational reasoning | Darus Colonies |

A copy of each puzzle appears in the Appendix. Each puzzle presented the student with a problem situation. The student was asked to answer a series of questions and explain how the answer was arrived at. In addition, after each answer, the student indicated how confident he/she was of

the answer, using a five point rating scale. The scale points were 0%, 25%, 50%, 75% and 100% confident.

2. Learning Style Inventory. This instrument was developed by Kolb (1977). A copy appears in the Appendix. It is a nine-item, self-descriptive inventory designed to measure a student's preferred mode of learning. Learning modes included preference for (1) Concrete Experience, (2) Reflective Observation, (3) Abstract Conceptualization, and (4) Active Experimentation. The inventory yields two combination scores: (1) preference for abstract over concrete experience; and (2) preference for active experimentation over reflective observation. As can be seen in the Learning Style Grid (see Figure 1), by determining each student's combination score, the student can be classified into one of four Learning Styles: (1) Accommodator, (2) Diverger, (3) Converger, and (4) Assimilator.

It was expected that students who had a strong preference for the active experimentation and concrete experience modes of learning (Accommodators) would be more receptive to the types of learning experiences provided in the course than those with other learning styles. It was also of interest to see how student learning mode preferences changed over the course of the semester.

Results -- Formal Operational Measures

The performance of the students on the formal operational measures is summarized in Table 1. Students showed some improvement on the tests of hypothetical-deductive reasoning, isolation and control of variables,

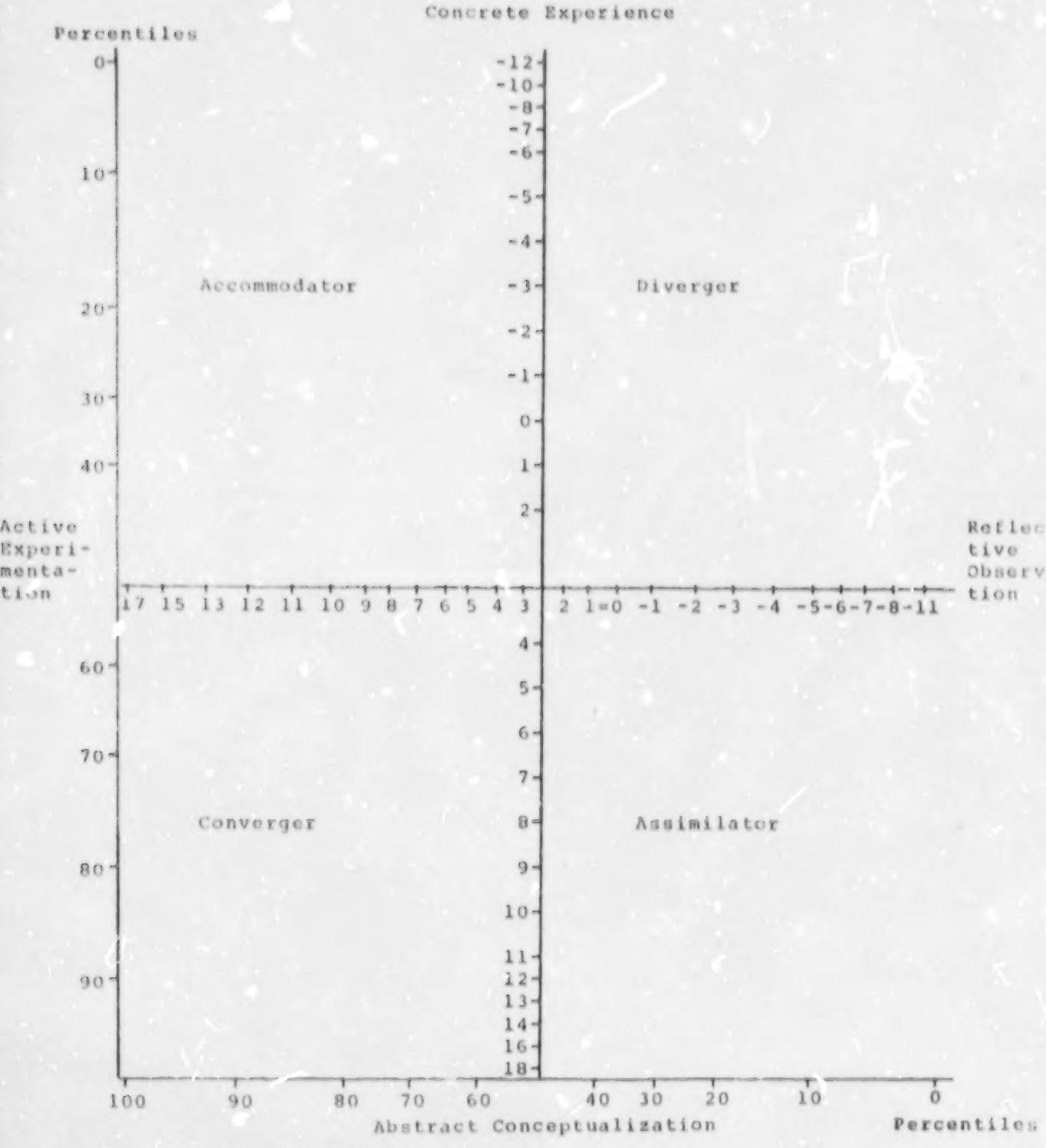



Figure 1. Learning Style Grid

and combinatorial reasoning. None of these changes were statistically significant. There was no change in performance in proportional reasoning or correlational reasoning.

The average change in total score from pre- to post-test was 2.15 points (s.d. = 7.87) with a range of -13 to +22.

There was a change in confidence (or student perception) of correctness of performance on all five formal operations measures and for the total test. Students were above the 50% confidence level on the formal measures at the start of the semester and became even more confident by the close of the semester.

What is of importance is the relationship (or correlation) between the actual performance and the student's perception of the correctness of performance. It was expected that there would be an increased match (or a stronger correlation) between these two measures over the course of the semester. This was the case for isolation and control of variables and proportional reasoning. The improved correlation occurred independent of whether or not there was a change in performance on the measure. That is, for isolation and control of variables, performance improved and the match between performance and student's perception of their performance increased. There was no change in performance on proportional reasoning but the match between actual performance and perception of performance increased.

Table 1

SUMMARY OF PERFORMANCE ON FORMAL OPERATIONAL MEASURES

Fall 1978 Sample
(n=13)

| Ability | | Response Pre | Response Post | | Confidence Rating Pre | Confidence Rating Post | | Correlation (Response/Confidence) Pre | Correlation (Response/Confidence) Post |
|---|---|---|---|---|---|---|---|---|---|
| 1. Hypothetical-Deductive Reasoning | $\bar{x}$ | 4.08 | 4.62 | $\bar{x}$ | 76% | 87% | r= | .46 | .45 |
| | s.d. | 1.93 | 1.56 | | | | | | |
| 2. Isolation & Control of Variables | $\bar{x}$ | 9.15 | 9.69 | $\bar{x}$ | 76% | 96% | r= | -.06 | .85 |
| | s.d. | 1.46 | 1.84 | | | | | | |
| 3. Combinatorial Reasoning | $\bar{x}$ | 10.31 | 11.38 | $\bar{x}$ | 66% | 90% | r= | .74 | -.01 |
| | s.d. | 5.70 | 6.32 | | | | | | |
| 4. Proportional Reasoning | $\bar{x}$ | 1.00 | 1.00 | $\bar{x}$ | 52% | 72% | r= | .39 | .76 |
| | s.d. | .82 | .82 | | | | | | |
| 5. Correlational Reasoning (8) | $\bar{x}$ | 3.69 | 3.69 | $\bar{x}$ | 78% | 87% | r= | -.08 | -.15 |
| | s.d. | 1.80 | 1.55 | | | | | | |
| 6. Total (43) | $\bar{x}$ | 28.23 | 29.15 | | 69.60 | 87.40 | | | |
| | s.d. | 8.14 | 8.21 | | | | | | |

There was essentially no change in the correlation between performance and student's perception of the correctness of performance for hypothetical-deductive reasoning; there was a decrease in the correlation for combinatorial reasoning and correlational reasoning.

Results -- Learning Style Inventory

The pre and post Learning Style Inventory preferences are summarized in Table 2. Twelve students completed the inventory at both measurement points. Results on the concrete experience-abstract conceptualization combination score are examined first. On the pre measure, 9 students showed a preference for concrete experience while 3 preferred abstract conceptualization. On the post measure, 4 students preferred concrete experience while 8 preferred abstract conceptualization. Thus there was a shift toward a more abstract mode of learning.

Results for the active experimentation-reflective observation combination score also showed a shift from pre to post measure. On the pre measure, 5 students indicated a preference for active experimentation, 7 for reflective observation. On the post measure, 8 preferred active experimentation and 4 preferred reflective observation. Thus there was a change in the direction of preferring active learning experiences.

It was of interest to determine if there was a relationship between learning style preference and performance in the course. Using the total score on the Formal Operational Measures, a change score based on the

Table 2

SUMMARY OF LEARNING STYLE INVENTORY LEARNING MODE PREFERENCES

Fall 1978 Sample

Learning Mode Preference

| | Concrete Experience ↔ Abstract Conceptualization | | Active Experimentation ↔ Reflective Observation | |
|---|---|---|---|---|
| Pre | 9[a] | 3 | 5 | 7 |
| Post | 4 | 8 | 8 | 4 |

[a] number of students (out of 12) indicating a preference

difference between pre and post total was calculated for each subject. Each subject was also classified into one of four learning styles on the Learning Style Inventory (see Figure 1).

The mean change score for each style was as follows: (1) Accommodator: + 0.67 (n=3); (2) Diverger: +,4.83 (n=6); (3) Converger: - 5.50 (n=2); and (4) Assimilator: + 4.00 (n=1). It can be seen that the greatest positive gains over the semester was made by those classified as Divergers and Assimilators, that is, those who preferred either concrete experience and reflective observation or abstract conceptualization and reflective observation.

These results were not consistent with the original assumption that the greatest gains would be made by

Accommodators (those preferring concrete experience and active experimentation).

Recommendations for Spring 1979 Evaluation

Based upon the results of the Fall semester evaluation and discussion among project staff, the following changes were made in the Spring 1979 evaluation design:

1. It was decided to drop the Learning Style Inventory from the design. Questions of validity and reliability of the instrument raised issues of its effective use for this project.
2. It was decided to include a standardized test of critical thinking. The Watson-Glaser Critical Thinking Appraisal was selected. It is an instrument which has been normed on a national sample of college students. There are parallel forms to the test. Since the project is still in the pilot phase, no control or comparison group was to be used in the Fall or Spring evaluations. The Watson-Glaser would allow for a comparison of student changes with a national sample.
3. To increase measurement reliability, it was decided to include more measures of formal operational thinking. Three additional puzzles were included.
4. In order to find out more about the students enrolled in the course, a modified version of the Educational Testing Service Student

Descriptive Questionnaire was added to the evaluation design.

PROJECT EVALUATION (Spring 1979 Evaluation)

Students

Sixteen students completed the course. Nine were males, seven females. The average was 19.69 years (age range 17-24 years). Further information about these students was obtained from responses to items selected from the ETS Student Descriptive Questionnaire. This information is summarized in Table 3.

Table 3

CHARACTERISTICS OF STUDENTS

Spring 1979 Sample
(n=16)

| Student Characteristic | | | | |
|---|---|---|---|---|
| Year in School | Freshman | Sophomore | Junior | |
| | 6 | 8 | 2 | |
| Ethnicity | Anglo | Black | Mex.-American | Oriental |
| | 9 | 2 | 3 | 2 |
| Major | Undeclared | Business | Biology | Comp. Sci. |
| | 4 | 2 | 3 | 2 |
| | Engineering | Mathematics | Physics | |
| | 2 | 2 | 1 | |
| High School GPA | A | B | C | |
| | 5 | 9 | 2 | |

Table 3 Continued

| High School Program | College Prep | Non-College Prep |
|---|---|---|
| | 15 | 1 |

| Year of High School Graduation | 1979 | 1978 | 1977 | 1976 | 1975 or earlier |
|---|---|---|---|---|---|
| | 1 | 4 | 7 | 2 | 2 |

| Feeling About High School Preparation in: | Very Well | Fairly Well | Poorly |
|---|---|---|---|
| Mathematics | 4 | 5 | 7 |
| Reading & Composition | 5 | 7 | 4 |
| Foreign Languages | 5 | 5 | 6 |
| Science | 3 | 9 | 4 |
| History, Social Science | 4 | 9 | 3 |
| Vocational Skills | 3 | 7 | 6 |
| Musical & Artistic Skills | 2 | 5 | 9 |
| Study Habits | 2 | 6 | 8 |

Student Characteristic

| Average Number of Semesters of High School Instruction | Biology | Mathematics | Chemistry | Physics |
|---|---|---|---|---|
| | 1.81 | 5.38 | 1.00 | 0.75 |

| | Earth Science | Life or Physical Science | Computer Science |
|---|---|---|---|
| | 0.25 | 0.63 | 0.00 |

| Need for Special Tutoring in: | Have Had | Will Need | Not Apply |
|---|---|---|---|
| English | 2 | 1 | 13 |
| Reading | 0 | 2 | 14 |
| Mathematics | 8 | 5 | 3 |
| Social Studies | 0 | 1 | 15 |
| Science | 1 | 8 | 7 |
| Foreign Language | 1 | 3 | 12 |

| Highest Degree Intend to Obtain | None | Bachelor's | Master's | M.D. |
|---|---|---|---|---|
| | 2 | 5 | 7 | 2 |

Table 3 Continued

Parents Formal Education

| | Grammar School | H.S. Grad | Some College | College Grad. | Some Grad Training |
|---|---|---|---|---|---|
| Father | 1 | 2 | 2 | 6 | 1 |
| Mother | 3 | 7 | 3 | 3 | 0 |

| | Grad or Prof. Degree |
|---|---|
| Father | 4 |
| Mother | 0 |

| Hours Per Week of Work | None | ≤6 | 11-15 | 16-20 | 21-25 | 26-30 |
|---|---|---|---|---|---|---|
| | 2 | 2 | 3 | 5 | 2 | 2 |

Evaluation Instruments

Students were assessed for their formal thinking abilities using two types of instruments: (1) Formal Operational Measures, and (2) Watson-Glaser Critical Thinking Appraisal. Each instrument was administered both at the beginning and end of the semester.

1. Formal Operational Measures. There were eight puzzles, each designed to assess one of the five formal thinking abilities. These were adapted from Campbell (1977). Performance on these puzzles was a direct measure of how well the course was meeting its stated objectives. The eight puzzles and the corresponding abilities assessed were:

| Formal Operational Ability | Puzzle |
|---|---|
| 1. Hypothetical-deductive reasoning | Islands Puzzle |
| 2. Isolation and control of variables | Growing Healthy Plants<br>Meal Worm Puzzle<br>Plants |

| Formal Operational Ability | Puzzle |
|---|---|
| 3. Combinatorial reasoning | Chemicals Task |
| 4. Proportional reasoning | Balance Task<br>Projection of Shadows |
| 5. Correlational reasoning | Darus Colonies |

A copy of each puzzle appears in the Appendix. For each puzzle, the student was presented with a problem situation, asked to answer a series of questions, and explain how the answer was arrived at. After each answer, the student rated his/her confidence in the correctness of answer using a five point rating scale (0%, 25%, 50%, 75% and 100% confident).

For each puzzle, students were asked to (a) solve the problem presented, (b) explain the solution, and (c) rate their confidence in the correctness of solution. The confidence ratings were made on a 5 point scale ranging from 0% to 100% confidence in the correctness of the response.

2. Watson-Glaser Critical Thinking Appraisal. This test assesses students' critical thinking abilities in five areas: (1) making inferences; (2) recognizing assumptions; (3) making deductions; (4) making interpretations; and (5) evaluating arguments (Watson & Glaser, 1964). The test format is multiple choice. There are 2 forms to the test. The YM form was given in the pre evaluation, the ZM in the post. Since raw scores on the ZM form are typically somewhat lower, these scores were converted so as to be equivalent to the YM scale scores. In addition, percentile rank equivalents to raw scores were determined.

Results -- Formal Operational Measures

Performance of the students on the formal operational measures is summarized in Table 4. Students improved on the measure of hypothetical-deductive reasoning. One measure of isolation and control of variables (Growing Healthy Plants Puzzle), combinatorial reasoning, and one measure of proportional reasoning (Projection of Shadows Puzzle). Only the change on the combinatorial reasoning task was statistically significant, $t = 4.31$, 15 d.f., $p < .005$. There was no change in performance on the Plants Puzzle, a measure of ability to isolate and control variables. And there was a slight decrease (statistically not significant) on one measure of isolation and control of variables (Meal Worm Puzzle), one measure of proportional reasoning (Balance Puzzle), and correlational reasoning. On the total test, there was a significant increase in performance over the semester, $t = 2.98$, 15 d.f., $p < .01$.

The pre-test measures of confidence in correctness of responses showed that, on the average, students were above the 50% level of confidence on all individual measures and the total test. On the post-test, average confidence ratings were above the 65% level on all individual measures and the total test. Thus, the students did become more confident over the course of the semester.

On the total test, there was an increase in the relationship (or correlation) between performance on the formal operational measures and students' perception of correctness of performance. Changes on four of the eight

Table 4

SUMMARY OF PERFORMANCE
ON FORMAL OPERATIONAL MEASURES

Spring 1979 Sample
(n=16)

Ability 1. Hypothetical-deductive reasoning

| Measure | Island Puzzle Responses(6) | | | Confidence Rating | | Correlation (Response/Confidence) | |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Pre | Post |
| $\bar{x}$ | 3.31 | 3.75 | + .44 | 73% | 81% | r= .11 | .54 |
| s.d. | 1.62 | 1.61 | | | | | |

Ability 2. Isolation and Control of Variables

| Measure | Growing Healthy Plants(12) | | | Confidence Rating | | Correlation (Response/Confidence) | |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Pre | Post |
| $\bar{x}$ | 9.44 | 9.94 | + .50 | 81% | 88% | r=-.01 | .69 |
| s.d. | 1.75 | 1.95 | | | | | |

| | Mealworm Puzzle(3) | | | Confidence Rating | | Correlation (Response/Confidence) | |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Pre | Post |
| $\bar{x}$ | 1.94 | 1.81 | - .125 | 70% | 82% | r= .47 | .11 |
| s.d. | .93 | 1.05 | | | | | |

| | Plants(2) | | | Confidence Rating | | Correlation (Response/Confidence) | |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Pre | Post |
| $\bar{x}$ | 1.94 | 1.94 | 0 | 92% | 86% | r= .30 | .13 |
| s.d. | .25 | .25 | | | | | |

Ability 3. Combinatorial Reasoning

| Measure | Chemicals (15) | | | Confidence Rating | | Correlation (Response/Confidence) | |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Pre | Post |
| $\bar{x}$ | 10.00 | 14.31 | +4.31 | 78% | 86% | r= .09 | .61 |
| s.d. | 4.56 | 1.45 | | | | | |

Ability 4. Proportional Reasoning

| Measure | Balance(3) | | | Confidence Rating | | Correlation (Response/Confidence) | |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Pre | Post |
| $\bar{x}$ | 1.50 | 1.25 | - .25 | 53% | 76% | r= .51 | .43 |
| s.d. | 1.03 | 1.29 | | | | | |

Table 4 Continued

| | Projection of Shadows(3) | | | Confidence Rating | | Correlation (Response/Confidence) | |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Pre | Post |
| $\bar{x}$ | 1.69 | 1.75 | + .06 | 56% | 67% | r= .16 | .66 |
| s.d. | 1.25 | 1.29 | | | | | |

Ability 5. Correlational Reasoning

Measure

| | Darus Colony(8) | | | Confidence Rating | | Correlation (Response/Confidence) | |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Pre | Post |
| $\bar{x}$ | 4.25 | 3.88 | - .375 | 73% | 79% | r=-.02 | -.11 |
| s.d. | 2.29 | 2.25 | | | | | |

| | Total Formal Operational Tasks(57) | | | Confidence Rating | | Correlation (Response/Confidence) | |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Pre | Post |
| $\bar{x}$ | 36.44 | 41.19 | +4.75 | 70% | 80% | r= .22 | .38 |
| s.d. | 9.29 | 7.45 | | 13.51 | 6.42 | | |

individual measures seem to account for this. An increase in the correlation occurred for the measure of hypothetical-deductive reasoning, one measure of isolation and control of variables (Growing Healthy Plants Puzzle), combinatorial reasoning, and one measure of proportional reasoning (Projection of Shadows Puzzle). For each measure, there was an increase in performance and confidence rating over the semester.

There was a decrease in the correlation for two measures of isolation and control of variables (the Meal Worm and Plants Puzzles), one measure of proportional reasoning (Balance Puzzle), and correlational reasoning. For all but the Plants Puzzle, there was a mean decrease in performance and an increase in confidence over the semester. For the Plants Puzzle, there was no change in performance and a decrease in confidence.

Results -- Watson-Glaser Critical Thinking Appraisal

Performance on the Watson-Glaser is summarized in Table 5. Analysis of the change in performance (using raw scores) showed a significant increase in the critical thinking abilities of the students, $t = 1.87$, 15 d.f., $p < .05$. Examination of the percentile ranks indicated the students were below the 50th percentile on the pre-test ($\bar{x} = 43.5$) and above the 50th percentile on the post-test ($\bar{x} = 60$).

Relationship Between Formal Operational Measures and Watson-Glaser Critical Thinking Appraisal

The correlation between the total scores of the formal

Table 5

SUMMARY OF WATSON-GLASER PERFORMANCE

| | Raw Scores (100) | | | Percentile Rank | |
|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post |
| Form | YM | ZM[a] | | | |
| $\bar{x}$ | 69.13 | 73.31 | + 4.19 | 43.5 | 60 |
| s.d. | 10.90 | 10.35 | 8.98 | | |
| n | 16 | 16 | | | |

[a] ZM raw scores were converted to the form YM scale.

operational measures and the raw scores of the Watson-Glaser was calculated. For the pre-testing, the correlation was + .71, for the post-testing + .66. Thus there was a moderate relationship between performance on the two measures with approximately 50% of the variability in common on the pre-testing, and 44% on the post-testing.

Recommendations for Fall 1979 Evaluation

On the basis of discussions among the project staff and the results of the Spring evaluation, the Fall 1979 evaluation design will be as follows:

1. It is evident that changes over the semester can not be interpreted without the inclusion of a comparison or control group. A control group will be included in the evaluation. It will be

made up of students not enrolled in the course. These students will be matched on pre-test Watson-Glaser Test scores and Fall semester program of study.

2. The assessment instruments will again include the Student Descriptive Questionnaire, the Watson-Glaser Critical Thinking Appraisal, and the Formal Operational Measures. These measures will be administered to the experimental and control groups in a pre-post evaluation design.
3. There will be two changes in the formal operational measures. First, three additional measures will be included so as to increase the reliability of the measure. There will be one more measure of each of the following abilities: hypothetical-deductive reasoning, isolation and control of variables, and combinatorial reasoning. Secondly, a new scoring procedure will be developed. All measures will be scored on a 5 point scale corresponding to levels of reasoning as described by Piaget (pre-operational to fully formal operational). This will allow for direct comparisons across the individual measure and ensure equal weighting of each measure in the total test score.

Hopefully the course should have far reaching effects for undergraduate science education. It can help develop the intellectual ability of science majors at the university level. A student who completes this course can return to his particular

discipline assured that he has acquired some abstract reasoning skills. These thinking skills should enable him to cope more effectively with upper division science courses, become a more independent thinker and a more effective problem solver. There is less chance of dropping science courses, becoming discouraged and changing majors, as happens to many potential science students. A student acquiring these reasoning skills can perform cognitively better than most science students who have not been exposed to this learning process.

A second outcome is the impact for curriculum design this course could have on all levels of science instruction. For the first time, curriculum can be developed in terms of thinking skills rather than course content. This unique approach could unify science instruction around conceptual schemes rather than separate disciplines.

This course could also have a strong effect upon the non-science major. As a result, a non-science major exposed to this program can acquire these reasoning skills and return to his particular discipline as a more productive thinker.

If the university is to produce students who are logical thinkers, life-long learners, rational decision-makers and independent problem-solvers, their learning experiences must be so designed to enhance intellectual development.

## References

Campbell, T. C. An evaluation of a learning cycle intervention strategy for enhancing the use of formal operational thought by beginning college physics students. Unpublished doctoral dissertation, University of Nebraska, 1977.

Kolb, D. A. Learning Style Inventory. Boston: McBer and Co., 1977.

Watson, G. and Glaser, E. M. Critical Thinking Appraisal Manual. Harcourt, Brace, and World, 1964.

# APPENDIX

## MODIFIED VERSION OF FLANDERS INTERACTION INSTRUMENT

# INTERACTION CATEGORY CODES

## Student Behaviors

| Code | Behavior |
|---|---|
| 0 | Miscellaneous |
| 1 | Working by self |
| 2 | Observing teacher |
| 3 | Observing student(s) |
| 4 | Interacting with teacher |
| 5 | Interacting with student(s) |
| 6 | Daydreaming |

## Teacher Behaviors

| Code | Behavior |
|---|---|
| 0 | Not interpretable |
| 1 | Doesn't observe students |
| 2 | Observes students, no interaction |
| 3 | Directs or gives information |
| 4 | Asks questions, suggests alternatives |
| 5 | Accepts, encourages |
| 6 | Rejects |
| 7 | Miscellaneous |

# SAMPLE RECORDING SHEET

Observer _____ Lesson Phase _____ Date _____

Instructor _____ Lesson Title _____ Pg. _____

STUDENT [a]

| | 0 | 1 self | 2 teacher observing | 3 student observing | 4 teacher interacting | 5 student interacting | 6 day/dreaming |
|---|---|---|---|---|---|---|---|
| start | | | | | | | |
| | 1 | | | | | | |
| name | 2 | | | | | | |
| | 3 | | | | | | |
| | 4 | | | | | | |
| | 5 | | | | | | |
| | 6 | | | | | | |
| | 0 | | | | | | |
| name | 1 | | | | | | |
| | 2 | | | | | | |
| | 3 | | | | | | |
| | 4 | | | | | | |
| | 5 | | | | | | |
| | 6 | | | | | | |
| | 0 | | | | | | |
| name | 1 | | | | | | |
| | 2 | | | | | | |
| | 3 | | | | | | |
| | 4 | | | | | | |
| | 5 | | | | | | |
| | 6 | | | | | | |
| | 0 | | | | | | |
| name | 1 | | | | | | |
| | 2 | | | | | | |
| | 3 | | | | | | |
| | 4 | | | | | | |
| | 5 | | | | | | |
| | 6 | | | | | | |
| end | | | | | | | |

TEACHER [b]

| | 0 | 1 doesn't observe | 2 observe/ no response | 3 gives info | 4 asks questions | 5 encourages | 6 rejects | 7 interacts w/student |
|---|---|---|---|---|---|---|---|---|
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| | 3 | | | | | | | |
| | 4 | | | | | | | |
| | 5 | | | | | | | |
| | 6 | | | | | | | |
| | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| | 3 | | | | | | | |
| | 4 | | | | | | | |
| | 5 | | | | | | | |
| | 6 | | | | | | | |
| | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| | 3 | | | | | | | |
| | 4 | | | | | | | |
| | 5 | | | | | | | |
| | 6 | | | | | | | |
| | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| | 3 | | | | | | | |
| | 4 | | | | | | | |
| | 5 | | | | | | | |
| | 6 | | | | | | | |

[a] enter L for lesson related

[b] enter T for total group, S for

# APPENDIX

## STUDENT LESSON EVALUATION

Interview Schedule

Student Feedback Form

## Interview Schedule and Instructions

1. Use the last 5 minutes of the class period to conduct the interview.
2. Make sure each student present completes the feedback form.
3. Return the completed forms to Jeanne.
4. Listed below is your schedule for conducting the interviews.

| Date | Instructor |
|---|---|
| Wed., October 4 | Crowley |
| Mon., October 9 | Carlson |
| Wed., October 11 | Pagni |
| Mon., October 16 | Clapp |
| Wed., October 18 | Crowley |
| Mon., October 23 | Carlson |
| Wed., October 25 | Pagni |
| Mon., October 30 | Clapp |
| Wed., November 1 | Crowley |
| Mon., November 6 | Hiegel |
| Wed., November 8 | Pagni |
| Mon., November 13 | Clapp |
| Wed., November 15 | Crowley |
| Mon., November 20 | Hiegel |
| Wed., November 22 | Pagni |
| Mon., November 27 | Clapp |
| Wed., November 29 | Carlson |
| Mon., December 4 | Hiegel |
| Wed., December 6 | Pagni |
| Mon., December 11 | Clapp |
| Wed., December 13 | Carlson |

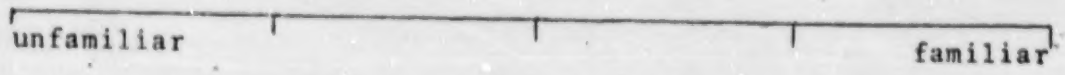
# CAUSE STUDENT FEEDBACK FORM

Lesson Title: _____

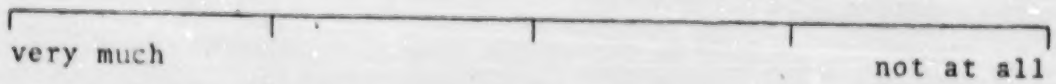
Instructor: _____

Date: _____

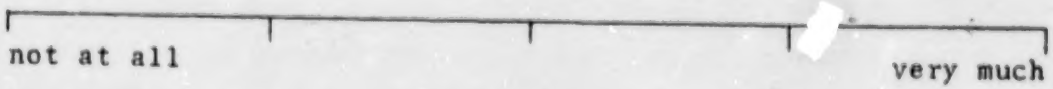
1. How familiar was the content?



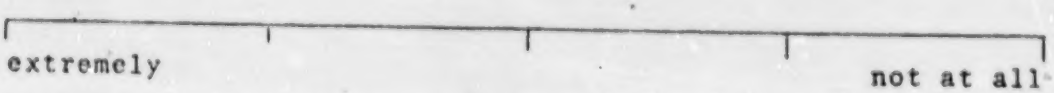

2. How much did you interact with the other students?




3. How much did you interact with the instructor?

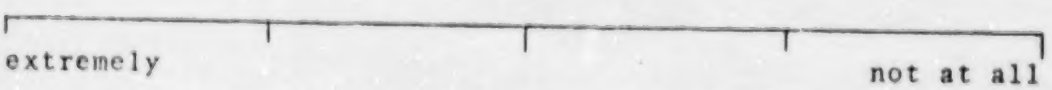



4. How interesting was the lesson?




5. Do you feel you learned some new science or mathematics in this lesson?

6. Did you find the lesson challenging?




7. In your opinion how did the lesson help you to <u>think</u>?

# APPENDIX

## SEQUENCE OF

## LESSONS IN COURSE

LESSON SEQUENCE

| | Content | Concept | Reasoning Skill |
|---|---|---|---|
| 1. | Chemistry | Hard Water | Combinatorial Reasoning |
| 2. | Mathematics | Area | Isolation and Control of Variables |
| 3. | Earth Science | Plate Tectonics | Hypothetical-deductive Reasoning |
| 4. | Mathematics | Computational Algorithms | Isolation and Control of Variables |
| 5. | Chemistry | Density of Liquids | Correlational Reasoning |
| 6. | Chemistry | Isomerism | Combinatorial Reasoning |
| 7. | Physics | Kinematics | Isolation and Control of Variables |
| 8. | Chemistry | Reactivity Series | Hypothetical-deductive Reasoning |
| 9. | Mathematics | Truth Tables | Hypothetical-deductive Reasoning |
| 10. | Physics | Center of Mass | Proportional Reasoning |
| 11. | Mathematics | Curve Fitting | Correlational Reasoning |
| 12. | Chemistry | Chemical Reaction | Combinatorial Reasoning |
| 13. | Earth Science | Friction | Isolation and Control of Variables |
| 14. | Chemistry | Lewis Structure | Hypothetical-deductive Reasoning |
| 15. | Mathematics | Hypothesis Testing | Hypothetical-deductive Reasoning |
| 16. | Earth Science | Sizes and Distances of Astronomical Objects | Proportional Reasoning |
| 17. | Earth Science | Inverse-Square Law | Proportional Reasoning |

| | Content | Concept | Reasoning Skill |
|---|---|---|---|
| 18. | Mathematics | Counting Principle | Combinatorial Reasoning |
| 19. | Chemistry | Reaction Variables | Isolation and Control of Variables |
| 20. | Chemistry | Molecular Weights and Formulae | Hypothetical-deductive Reasoning |
| 21. | Mathematics | Sequence | Hypothetical-deductive Reasoning |
| 22. | Physics | Gas Laws | Proportional Reasoning |
| 23. | Mathematics | Permutations and Combinations | Combinatorial Reasoning |
| 24. | Physics | Hydrodynamics | Isolation and Control of Variables |
| 25. | Physics | Centripetal Force | Hypothetical-deductive Reasoning |
| 26. | Mathematics | Axioms and Postulates | Hypothetical-deductive Reasoning |
| 27. | Mathematics | Statistical Inference | Proportional Reasoning |
| 28. | Chemistry | Physical Structures | Correlational Reasoning |
| 29. | Mathematics | Binomial Coefficients | Combinatorial Reasoning |
| 30. | Mathematics | Graphing | Isolation and Control of Variables |
| 31. | Physics | Heat | Hypothetical-deductive Reasoning |
| 32. | Mathematics | Conditional Reasoning | Hypothetical-deductive Reasoning |
| 33. | Earth Science | Rate of Weathering | Proportional Reasoning |
| 34. | Physics | Electric Circuits | Combinatorial Reasoning |

| | Content | Concept | Reasoning Skill |
|---|---|---|---|
| 35. | Chemistry | Periodic Table | Hypothetical-deductive Reasoning |
| 36. | Mathematics | Hypergeometric Distribution | Proportional Reasoning |
| 37. | Chemistry | Reactant-Product Relationships | Correlational Reasoning |
| 38. | Mathematics | Inductive Proofs | Hypothetical-deductive Reasoning |
| 39. | Physics | Newtonian Mechanics | Proportional Reasoning |

APPENDIX

EVALUATION INSTRUMENTS

FALL 1978

Formal Operational Measures

Learning Style Inventory

Date _____

WRITTEN PUZZLES

Name _____ Age _____

Class (circle one) freshman sophomore junior senior other

Major _____

Directions:

This booklet consists of five written puzzles. Each puzzle presents you with a situation and asks that you answer a series of questions, explaining how you arrived at your answers. As you complete each question, please remember that you should attempt each part and answer each question as completely as you can, explaining how you arrived at the result.

Also, after each answer, you are to indicate how confident you are that your answer is correct. You are to circle the appropriate percentage from 0% to 100%. If you feel totally certain you are right, circle 100% for your confidence rating; if you feel absolutely certain you are wrong, circle 0% confident; if you feel you have an equal chance of being right or wrong, circle 50% confident.

If you have any questions concerning any of the puzzles, please come to the front of the class.

This is not a timed exercise and you should take about 45 minutes.

Name _____

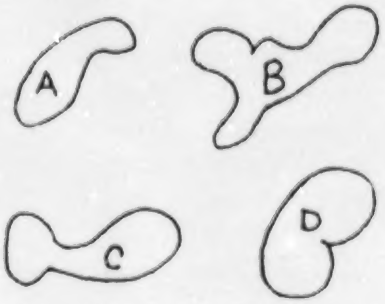
Date _____

# ISLANDS

The puzzle is about Islands A, B, C, and D in the ocean. People have been traveling among these islands by boat for many years, but recently an airline started in business. Carefully read the clues about possible plane trips at present. The trips may be direct or include stops and plane changes on an island. When a trip is possible, it can be made in either direction between the islands. You may make notes or marks on the map to help use the clues.

First Clue : People can go by plane between Islands C and D.

Second Clue: People cannot go by plane between Islands A and B, even indirectly.




Use these two clues to answer Question 1. Do not read the next clue yet.

Question 1:

Can people go by plane between Island B and D? Yes ___ No___
Can't tell from the two clues ___ Please explain your answer.

Confidence Rating: 0% 25% 50% 75% 100%

Third Clue: (do not change your answer to Question 1 now!)
People can go by plane between Islands B and D.

Use all three clues to answer Question 2 and 3.

Question 2:

Can people go by plane between Islands B and C? Yes___No___
Can't tell from the three clues___. Please explain your answer.

Confidence Rating: 0% 25% 50% 75% 100%

Question 3:

Can people go by plane between Islands A and C? Yes___No___
Can't tell from the three clues___. Please explain your answer.

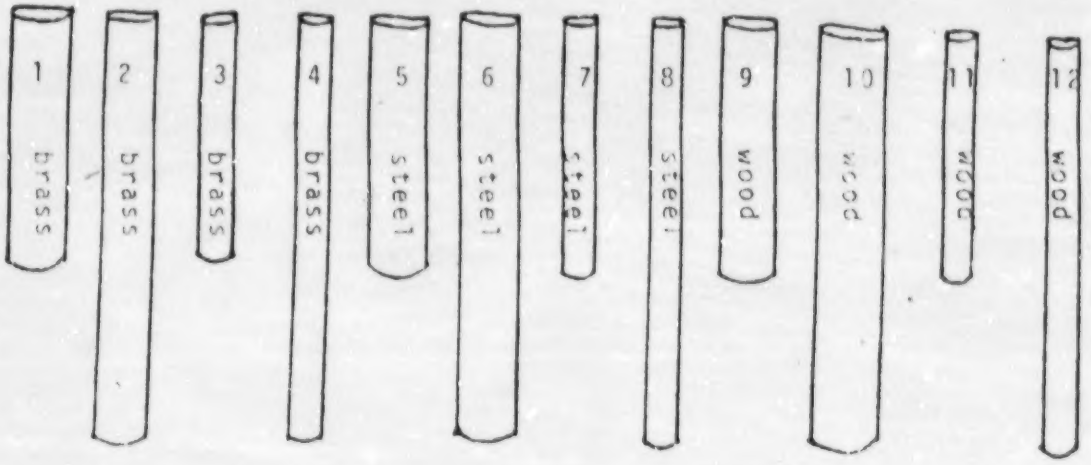
Confidence Rating: 0% 25% 50% 75% 100%

Name _____

Date _____

# FLEXIBILITY OF RODS

You are working on a problem involving flexibility of rods and are trying to figure out which is more flexible, long or short rods. You are working with the following rods.




1. Which two rods can you compare to find out if long rods bend more than short rods? Why did you choose those two rods to compare?

Confidence: 0% 25% 50% 75% 100%

2. Could you compare rods 2 and 3 to see if long rods bend more than short rods? Why or why not?

Confidence: 0% 25% 50% 75% 100%

3. What rods would you compare to find out if brass rods bend more than steel rods? Why did you choose those two rods to compare?

Confidence: 0% 25% 50% 75% 100%

4. Could you compare rods 1 and 7 to see if brass rods bend more than steel rods? Why or why not?

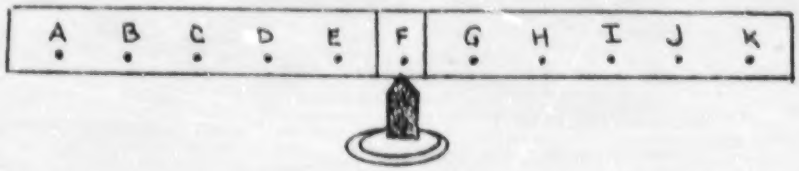
Confidence: 0% 25% 50% 75% 100%

Name _____

Date _____

# THE BALANCE

Suppose you are provided a balance similar to the one illustrated below. It consists of a long wooden balance arm with 11 marked holes (A-K) for hanging weights. The wooden arm is balanced on a pivot support (all the holes are evenly distributed over the length of the bar) at the center of the arm through hole F.




1. If a 5 weight

is hung at D, where must you hand a 2 weight

to balance the arm? Please explain carefully how you arrive at your answer.

Confidence Rating: 0% 25% 50% 75% 100%

2. A ten weight

is hung at C. What size weight must be hung at K to balance the wooden arm? Please explain how you found the answer.

Confidence Rating: 0% 25% 50% 75% 100%

3. A six weight

is hung at D. Where must you hang a four weight

to balance the arm? Please explain your answer.

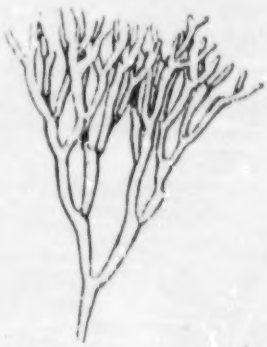
Confidence Rating: 0% 25% 50% 75% 100%

## ALGAE PUZZLE

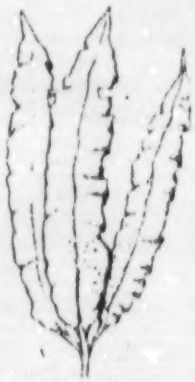
A population of crabs which eats algae lives on a seashore. On the seashore there are four kinds of algae: yellow, red, brown, and green algae.

Yellow - Y

Red - R



Green - G



Brown - B

Dr. Saltspray, a biologist, is interested in determining which of the types of algae are actually eaten by the crabs. He plans to find out by examining the stomach contents of the crabs. Before he does his investigation he lists every interesting possibility he thinks he may find in the stomachs. Write down every possibility he can find. Use letters Y, R, G, and B to save space.

Confidence Rating: 0% 25% 50% 75% 100%

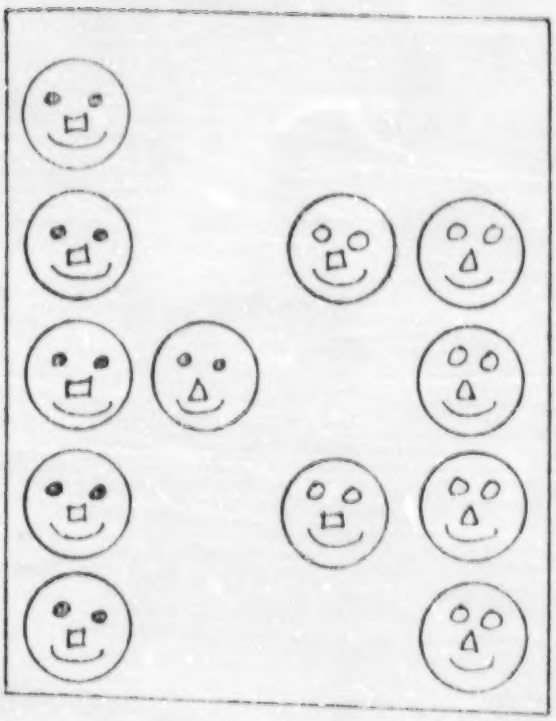
DARUS COLONIES

This task involves the relationship between eye color and nose shape of an animal "Darus."

Before visiting a Darus Colony, you are told that black eyes are usually associated with square-shaped noses. You want to establish whether or not this relationship holds true. In each of the colonies given below, please do the following:

a. Count the total number of cases which support or confirm this relationship.
b. Count the total number of cases which do not support or disconfirm this relationship.
c. State whether or not you think there is a relationship between eye color and nose shape, and why.

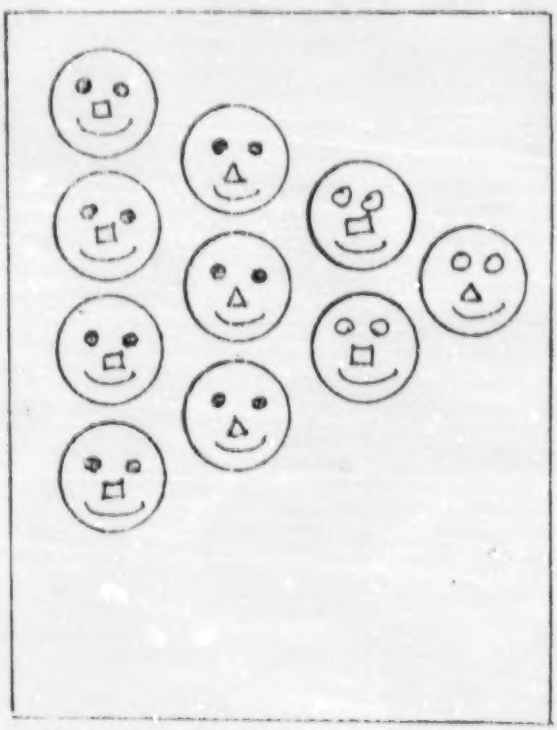
COLONY A



a. Number of supporting or confirming cases _____
b. Number of nonsupporting or nonconfirming cases _____
c. Are black eyes associated with square-shaped noses? Why?

Confidence: 0% 25% 50% 75% 100%

COLONY B



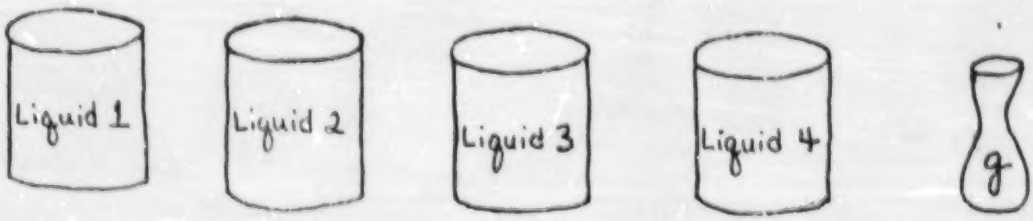
a. Number of supporting or confirming cases _____
b. Number of nonsupporting or nonconfirming cases _____
c. Is there a relationship between eye color and nose shape? Why?

Confidence: 0% 25% 50% 75% 100%

## Chemicals

This task involves combining chemicals to yield a red color. You are given four odorless, colorless liquids and a fifth beaker containing an activating solution. This activating solution (g) is always necessary to obtain the red reaction. Your task is to figure out which of these chemicals in combination with the activating solution (g) will yield the red color.

Write down all of the tests that you would conduct to find the red color. The order in which you combine chemicals is not important and the amount of each chemical used is not important. You may assume you have an endless supply of test tubes to use in this task.




Confidence Rating: 0% 25% 50% 75% 100%

# Instructions

There are nine sets of four words listed below. Rank order the words in each set by assigning a 4 to the word which best characterizes your learning style, a 3 to the word which next best characterizes your learning style, a 2 to the next most characteristic word and a 1 to the word which is least characteristic of you as a learner.

You may find it hard to choose the words that best characterize your learning style. Nevertheless, keep in mind that there are no right or wrong answers—all the choices are equally acceptable. The aim of the inventory is to describe how you learn, not to evaluate your learning ability.

*Be sure to assign a different rank number to each of the four words in each set; do not make ties.*

| | | | | |
|---|---|---|---|---|
| 1. | ___discriminating | ___tentative | ___involved | ___practical |
| 2. | ___receptive | ___relevant | ___analytical | ___impartial |
| 3. | ___feeling | ___watching | ___thinking | ___doing |
| 4. | ___accepting | ___risk-taker | ___evaluative | ___aware |
| 5. | ___intuitive | ___productive | ___logical | ___questioning |
| 6. | ___abstract | ___observing | ___concrete | ___active |
| 7. | ___present-oriented | ___reflecting | ___future-oriented | ___pragmatic |
| 8. | ___experience | ___observation | ___conceptualization | ___experimentation |
| 9. | ___intense | ___reserved | ___rational | ___responsible |

# Scoring

The four columns of words above correspond to the four learning style scales: CE, RO, AC, and AE. To compute your scale scores, write your rank numbers in the boxes below only for the designated items. For example, in the third column (AC), you would fill in the rank numbers you have assigned to items 2, 3, 4, 5, 8, and 9. Compute your scale scores by adding the rank numbers for each set of boxes.

| Score items: 2 3 4 5 7 8 | Score items: 1 3 6 7 8 9 | Score items: 2 3 4 5 8 9 | Score items: 1 3 6 7 8 9 |
|---|---|---|---|
| CE = _____ | RO = _____ | AC = _____ | AE = _____ |

To compute the two combination scores, subtract CE from AC and subtract RO from AE. Preserve negative signs if they appear.

AC − CE: [AC] − [CE] = _____

AE − RO: [AE] − [RO] = _____

# APPENDIX

## EVALUATION INSTRUMENTS

## SPRING 1979

### Formal Operational Measures

Date _____

WRITTEN PUZZLES

Name _____ Age _____

Class (circle one) freshman sophomore junior senior other

Major _____

Directions :

This booklet consists of eight written puzzles. Each puzzle presents you with a situation and asks that you answer a series of questions, explaining how you arrived at your answers. As you complete each question, please remember that you should attempt each part and answer each question as completely as you can, explaining how you arrived at the result.

Also, after each answer, you are to indicate how confident you are that your answer is correct. You are to circle the appropriate percentage from 0% to 100%. If you feel totally certain you are right, circle 100% for your confidence rating; if you feel absolutely certain you are wrong, circle 0% confident; if you feel you have an equal chance of being right or wrong, circle 50% confident.

If you have any questions concerning any of the puzzles, please come to the front of the class.

This is not a timed exercise.

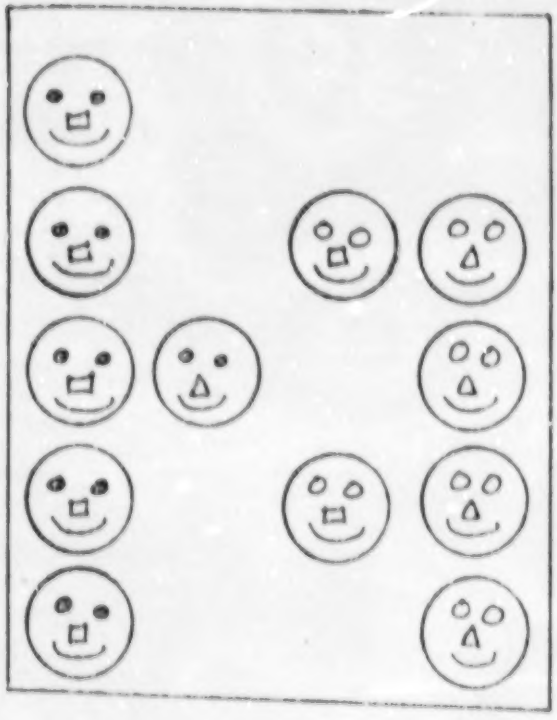
## DARUS COLONIES

This task involves the relationship between eye color and nose shape of an animal "Darus."

Before visiting a Darus Colony, you are told that black eyes are usually associated with square-shaped noses. You want to establish whether or not this relationship holds true. In each of the colonies given below, please do the following:

a. Count the total number of cases which support or confirm this relationship.
b. Count the total number of cases which do not support or disconfirm this relationship.
c. State whether or not you think there is a relationship between eye color and nose shape, and why.

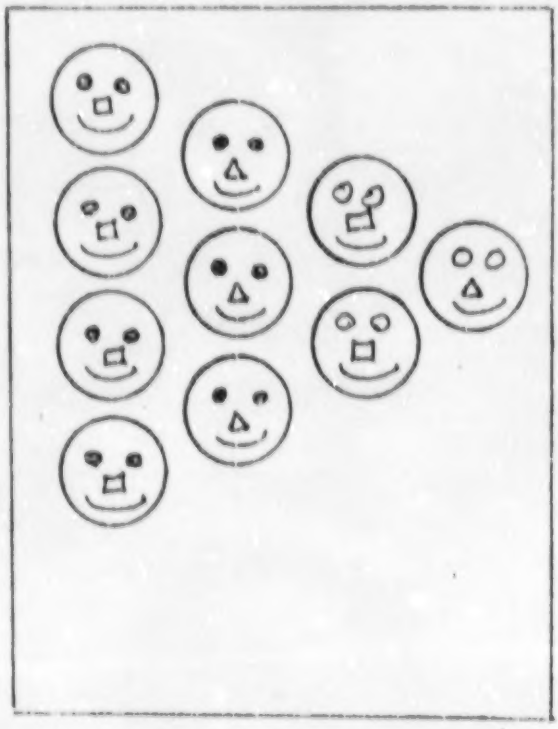
COLONY A



a. Number of supporting or confirming cases _____.
b. Number of nonsupporting or nonconfirming cases _____.
c. Are black eyes associated with square-shaped noses? Why:

Confidence: 0% 25% 50% 75% 100%

COLONY B

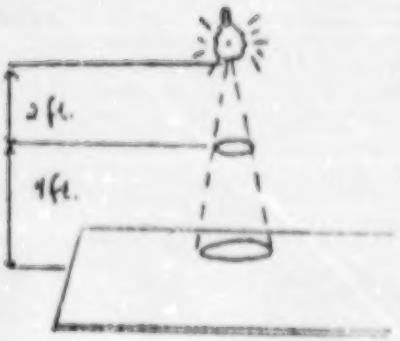


a. Number of supporting or confirming cases _____.
b. Number of nonsupporting or nonconfirming cases _____.
c. Is there a relationship between eye color and nose shape? Why?

Confidence: 0% 25% 50% 75% 100%

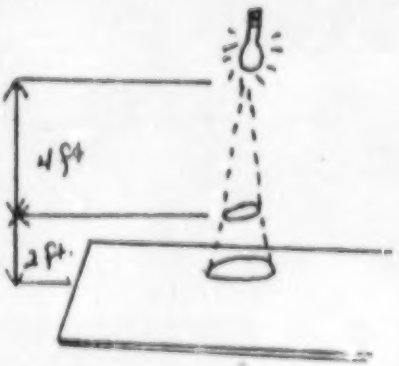
## Projection of Shadows

1. A ring 3 inches in diameter is 2 feet from the light and 4 feet from the table. The 3 inch ring has a nine inch shadow. Where should a 6 inch ring be placed to make the same size shadow? Please explain carefully how you arrive at your answer.




Confidence Rating: 0% 25% 50% 75% 100%

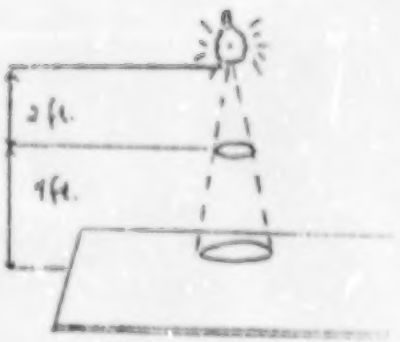
2. A ring 2 inches in diameter is 4 feet from the light and 2 feet from the table. It casts a shadow on the table. What size ring must be placed 3 feet from this light and 3 feet from the table so that it makes the same size shadow? Please explain how you found the answer.






Confidence Rating: 0% 25% 50% 75% 100%

3. A ring 3 inches in diameter is 2 feet from the light and 4 feet from the table. It casts a 9 inch shadow on the table. Where should a 4 inch ring be placed to make the same size shadow? Please explain how you found your answer.




Confidence Rating: 0% 25% 50% 75% 100%

PLANT

An experimenter wanted to test how plants respond to amount of water and color of plant food. To do this, she has been conducting an experiment for the past two months. Every week she has been treating plants A, B, C, and D as shown below.

The pictures show that a plant is healthy because of:

A. color of plant food but not amount of water.
B. amount of water but not color of plant food.
C. both color of plant food and amount of water.
D. neither color of plant food nor amount of water.

Please explain your choice. _____

_____

_____

_____

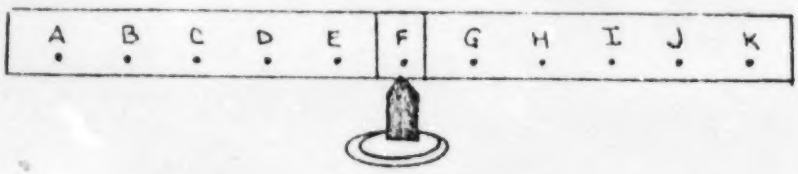
_____



Confidence Rating: 0% 25% 50% 75% 100%

## THE BALANCE

Suppose you are provided a balance similar to the one illustrated below. It consists of a long wooden balance arm with 11 marked holes (A-K) for hanging weights. The wooden arm is balanced on a pivot support (all the holes are evenly distributed over the length of the bar) at the center of the arm through hole F.




1. If a 5 weight

is hung at D, where must you hang a 2 weight

to balance the arm? Please explain carefully how you arrive at your answer.

   Confidence Rating: 0% 25% 50% 75% 100%

2. A ten weight

is hung at C. What size weight must be hung at K to balance the wooden arm? Please explain how you found the answer.

   Confidence Rating: 0% 25% 50% 75% 100%

3. A six weight

is hung at D. Where must you hang a four weight

to balance the arm? Please explain your answer.

   Confidence Rating: 0% 25% 50% 75% 100%

4. Can you provide a general rule for producing balance in the wooden arm for any two weights hung on the arm? Please explain your rule.

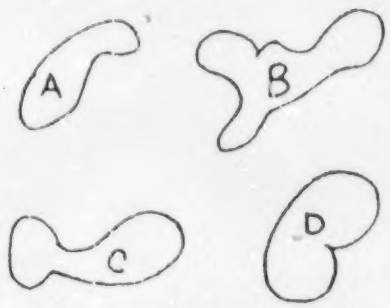
   Confidence Rating: 0% 25% 50% 75% 100%

# ISLANDS

The puzzle is about Islands A, B, C, and D in the ocean. People have been traveling among these islands by boat for many years, but recently an airline started in business. Carefully read the clues about possible plane trips at present. The trips may be direct or include stops and plane changes on an island. When a trip is possible, it can be made in either direction between the islands. You may make notes or marks on the map to help use the clues.

First Clue : People can go by plane between Islands C and D.

Second Clue: People cannot go by plane between Islands A and B, even indirectly.




Use these two clues to answer Question 1. Do not read the next clue yet.

Question 1:

Can people go by plane between Island B and D? Yes ___ No___
Can't tell from the two clues ___ Please explain your answer.

Confidence Rating: 0% 25% 50% 75% 100%

Third Clue: (do not change your answer to Question 1 now!)
People can go by plane between Islands B and D.

Use all three clues to answer Question 2 and 3.

Question 2:

Can people go by plane between Islands B and C? Yes___No___
Can't tell from the three clues___. Please explain your answer.

Confidence Rating: 0% 25% 50% 75% 100%

Question 3:

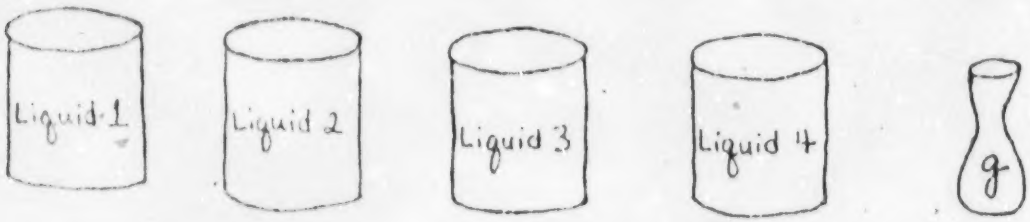
Can people go by plane between Islands A and C? Yes___No___
Can't tell from the three clues___. Please explain your answer.

Confidence Rating: 0% 25% 50% 75% 100%

## Chemicals

This task involves combining chemicals to yield a red color. You are given four odorless, colorless liquids and a fifth beaker containing an activating solution. This activating solution (g) is always necessary to obtain the red reaction. Your task is to figure out which of these chemicals in combination with the activating solution (g) will yield the red color.

Write down all of the tests that you would conduct to find the red color. The order in which you combine chemicals is not important and the amount of each chemical used is not important. You may assume you have an endless supply of test tubes to use in this task.




Confidence Rating: 0% 25% 50% 75% 100%

2. You find that the following tests yield no color.

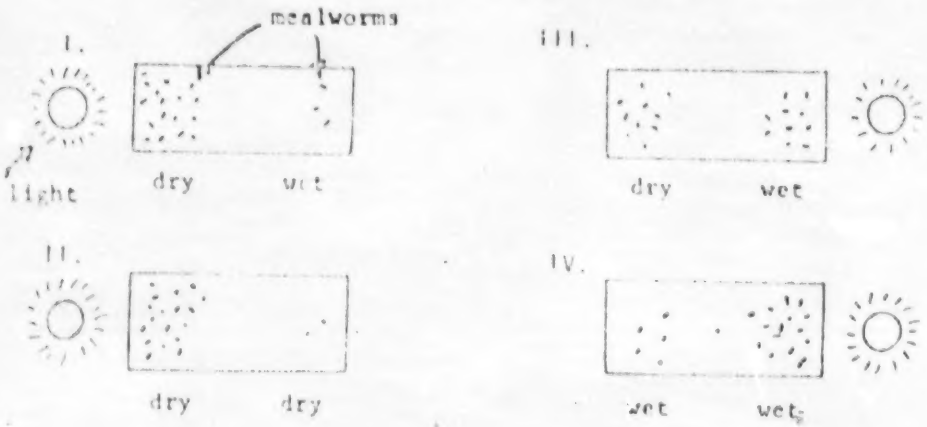
1 x g
2 x g
3 x g
4 x g
1 x 2 x g
1 x 3 x g
1 x 4 x g
3 x 4 x g
2 x 3 x g

However 2 x 4 x g yields the reddish color. You tell the experimenter you have found the solution. The experimenter asks you if there is any other way to obtain the color. What other tests would you conduct to see if any other combinations yield this color. Write them on this page.

Confidence Rating: 0% 25% 50% 75% 100%

MEALWORM

An experimenter wanted to test the response of mealworms to light and moisture. To do this he set up four boxes as shown in the diagram below. He used lamps for light sources and constantly watered pieces of paper in the boxes for moisture. In the center of each box he placed 20 mealworms. One day later he returned to count the number of mealworms that had crawled to the different ends of the boxes.




The diagrams show that mealworms respond to (response means move toward or away from):

A) light but not moisture.

B) moisture but not light.

C) both light and moisture.

D) neither light nor moisture.

Please explain your choice. _____

_____

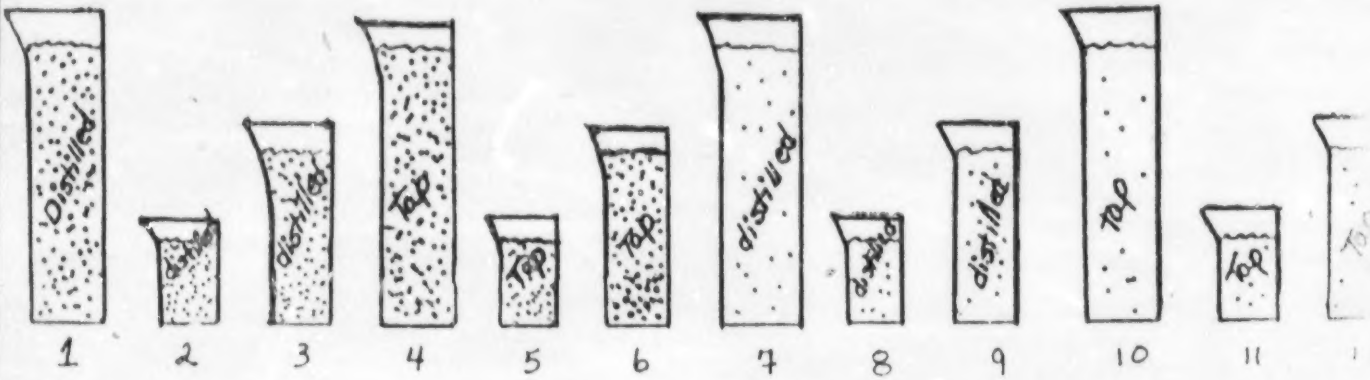
_____

_____

Confidence: 0% 25% 50% 75% 100%

# Growing Healthy Plants

You are working with a problem involving growing healthy plants and are trying to figure out what to add to a plant to make it healthy, distilled water or tap water. You are working with the following glasses:




Vitamins: ⊡

1. Which two glasses can you compare to find out if distilled water is better for plants than tap water? Why did you choose those two glasses?

   Confidence Rating: 0% 25% 50% 75% 100%

2. Could you compare glasses 3 and 12 to see if distilled water is better for plants than tap water? Why or why not?

   Confidence Rating: 0% 25% 50% 75% 100%

3. Which glasses can you compare to find out if a large glass is better for plants than a medium glass? Why did you choose those two glasses to compare?

   Confidence Rating: 0% 25% 50% 75% 100%

4. Could you compare glasses 1 and 9 to see if a large glass is better for plants than a medium glass? Why or why not?



   Confidence Rating: 0% 25% 50% 75% 100%